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Is the Standard Electroweak Theory Happy with $m_t \sim 174$ GeV?

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ABSTRACT

Based on the recent CDF report on the top-quark, we have carried out an analysis on the Higgs mass within the minimal standard electroweak theory using the latest data on the W-mass. Although this theory is in quite a happy situation now, we wish to point out that more precise measurements of M_W and m_t in the future are crucial and they could come to require some new physics beyond it.

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Recently, CDF collaboration at Fermilab Tevatron collider has reported evidence of top-quark pair productions [1]. There its mass has been estimated to be $m_t^{exp} = 174 \pm 16$ GeV. Its final establishment must come after D0 collaboration confirms their results, but this observation will surely work as a new strong experimental support to the minimal standard electroweak theory with three fermion generations (the electroweak theory, hereafter). It is also noteworthy that very heavy top ($\sim$ 160-180 GeV) has already been anticipated through analyses of low- and high-energy precision electroweak data [2] before the above CDF report.

It seems that the electroweak theory is in a very happy situation. This is true at present, but one might feel that the above m_t^{exp} is a little too heavy. In this short note, we have studied this problem briefly. As a result, we wish to point out that more precise determinations of m_t and M_W might bring us into another very stimulating situation. The important point is the m_ϕ(the Higgs-boson mass)-dependence of the M_W-M_Z relation derived from the μ-decay in the electroweak theory. We use here the M_W-M_Z formula given in [3], which has already been confirmed to be consistent with other calculations [4].

We start our discussion with summarizing phenomenological analyses on the Higgs mass. Ellis et al. obtained $m_\phi < 250$ GeV at 95 % C.L. independently of m_t [5]. The results by Novikov et al. in [2] and by Jacobsen [6] are both not so drastic, but still low m_ϕ is favored and 1σ region gives an upper bound $m_\phi \lesssim$ 200-300 GeV. (In the latter analyses, the recent SLD measurement of $\sin^2\theta_W^{eff}$ [7] is also used.)

However, this does not mean that all the electroweak quantities used there demand low-mass Higgs boson. Indeed, the central value of M_W^{exp} ($M_W^{exp} = 80.21 \pm 0.18$ GeV by UA2+CDF+D0 [8]) and that of m_t^{exp}(=174 GeV) require very heavy Higgs ($\sim$ 1.7 TeV) via the well-known relation

$$M_W^2 = \frac{1}{2}M_Z^2\left\{1+\sqrt{1-\frac{2\sqrt{2}\pi\alpha}{M_Z^2 G_F(1-\Delta r)}}\ \right\}, \tag{1}$$

where $\alpha = 1/137.036$, $G_F = 1.16639 \times 10^{-5}$ GeV^{-2}, $M_Z = 91.1899 \pm 0.0044$ GeV

[9], and Δr is the one-loop corrections to the μ-decay amplitude.[♯1] At present, it does not cause any serious trouble since m_ϕ as low as 80 GeV is also allowed if we take into account $\Delta m_t^{exp} = \pm 16$ GeV and $\Delta M_W^{exp} = \pm 0.18$ GeV.[♯2] That is, the m_ϕ-dependence of the M_W-M_Z relation is not strong. That is why χ^2 takes its minimum at low m_ϕ even when M_W^{exp} is taken into account in an analysis.

When LEP II starts, the W-mass is expected to be determined very precisely: $\Delta M_W^{exp} \sim \pm 0.05$ GeV [12]. We may also expect that m_t will eventually be measured with better precision. We assume here tentatively that $\Delta m_t^{exp} \sim \pm 5$ GeV will be possible in the near future. In this case, a constraint from the W-mass becomes much stronger. Concretely, $\Delta m_t^{exp} = \pm 5$ GeV produces an error of ± 0.03 GeV in the W-mass calculation. Combining this with $\Delta M_W^{exp} = \pm 0.05$ GeV and a theoretical ambiguity $\Delta M_W = \pm 0.03$ GeV (which has been a bit overestimated for safety), we can compute $M_W - M_W^{exp}$ with an error of about ± 0.07 GeV. As an example, let us assume that the central values of M_W^{exp} and m_t^{exp} do not change. Then, $M_W - M_W^{exp}$ becomes 0.13 ± 0.07 GeV for $m_\phi = 300$ GeV. It means that $m_\phi = 300$ GeV is ruled out at 1.9σ level within the minimal standard electroweak theory. Similarly, even $m_\phi = 600$ GeV is not allowed though at 1.1σ level ($M_W - M_W^{exp} = 0.08 \pm 0.07$ GeV). To be consistent with the data at 1σ level, m_ϕ has to be at least 650 GeV.

On the other hand, it is obvious that the upper bound on m_ϕ derived in analyses without M_W becomes lower than the one in those with M_W since M_W^{exp} itself favors high mass Higgs. This means that we are led to another very exciting situation: M_W^{exp} demands heavy Higgs: $m_\phi \gtrsim 650$ GeV, while the others need $m_\phi \lesssim 200$-300 GeV. As already mentioned, the central values of M_W^{exp} and m_t^{exp} demand $m_\phi \sim 1.7$ TeV. Even if we limit discussions to perturbation calculations, such extremely heavy Higgs will cause serious problems [13] (see also [14] and

[♯1] In actual calculations, m_t^2 term resummation [10] plus QCD corrections to the top-quark loop [11] have been taken into account in addition to Eq.(1).

[♯2] $M_W - M_W^{exp} = 0.22 \pm 0.21$ GeV and 0.21 ± 0.21 GeV for $m_\phi = 70$ GeV and 80 GeV respectively.

references cited therein).

It will be difficult to present this conclusion more strongly, e.g., at 3σ due to the well-known fact that low energy quantities do not have m_ϕ^2 terms at one-loop order [15]. Nevertheless, if a situation like that comes to be real, it must be quite interesting, and we may need to consider some new physics beyond the standard electroweak theory which makes opposite contribution to M_W and the other quantities. Precise measurements of M_W and m_t are therefore considerably significant.

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